

Behavior-Based Safety (BBS) as a novel aspect of the safety risk assessment at a tunnel construction site



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INTRODUCTION

- **Accidents at tunnel construction sites decreased in Japan.**
 - Development of construction technology
 - Promotion of machinery construction
- **Fatalities before NATM (earlier than 1978) ; >50
after NATM; around 10–20**
- **Many tunnel work-sites in Japan are
still dependent on workers attentiveness**
- **Tunneling methods have never been
quantitatively analyzed**
- **Important to analyze behavioral pattern**



PURPOSE OF THE PRESENT STUDY

- **Analysed movements of tunnelling workers and machines at a tunnel construction site in Japan.**
- **Dangerous points and moments were clarified.**

MATERIALS AND METHODS

- Used a video camera (HDM360MS, Panasonic, Japan) and recorded a work site at a face of tunnel in a tunnel construction site.
- The work at the tunnel construction site was excavated tunnel face.
- Counted number of workers and duration time existing at the face of tunnel.
- Heavy machines used around the face of tunnel including dump truck and fuel feed vehicle was counted and recorded.
- Calculated the ratio of the most dangerous work which was tunnel excavation within the whole work time.
- At the face of the tunnel, 6 workers, a drill machine, 2 tank trucks, 2 backhoes, 3 dump tracks, a fuel feed vehicle, and a tanker were existed at the site.

RESULTS

- Measured the number of workers and heavy machines at the face of the tunnel.
- The data of the workers and machines was counted by 2-minute pitches.
- We found that work near the face of the tunnel was clearly divided into 4 kinds, which were preparation (Fig.2A), transportation of the sand muck (Fig.2B and D), the face excavation of the tunnel (Fig.2C), and clearance of the day (Fig. 2E).
- Among these four works, the most dangerous one was the face excavation because workers often stood very close to heavy machines in the work.
- In the excavation of the face of the tunnel, the duration was 52 minutes, which was 13% in the whole work time of 6 hours and 33 minutes (Fig,3).
- We also found that overlap of the dump trucks was not happened in the tunnel.

Fig. 1A Preparation

| Time | Number of workers | Drill | Tank truck 1 | Tank truck 2 | Backhoe 1 | Dump truck 1 | Dump truck 2 | Oli feed vehicle | Dump truck 3 | Tanker | Backhoe 2 |
|----------|-------------------|-------|--------------|--------------|-----------|--------------|--------------|------------------|--------------|--------|-----------|
| 09:36:17 | 1 | | | | | | | | | | |
| 09:38:02 | 0 | | | | | | | | | | |
| 09:40:17 | 3 | | | | | | | | | | |
| 09:41:17 | 4 | | | | | | | | | | |
| 09:44:17 | 3 | | | | | | | | | | |
| 09:46:00 | 4 | | | | | | | | | | |
| 09:52:45 | 5 | | | | | | | | | | |
| 09:52:55 | 4 | | | | | | | | | | |
| 09:56:40 | 3 | | | | | | | | | | |
| 09:58:02 | 4 | | | | | | | | | | |
| 10:00:57 | 5 | | | | | | | | | | |
| 10:01:27 | 4 | | | | | | | | | | |
| 10:02:05 | 5 | | | | | | | | | | |
| 10:09:58 | 3 | | | | | | | | | | |
| 10:12:25 | 4 | | | | | | | | | | |
| 10:28:51 | 3 | | | | | | | | | | |
| 10:46:04 | 4 | | | | | | | | | | |
| 10:47:04 | 5 | | | | | | | | | | |
| 10:54:24 | 6 | | | | | | | | | | |
| 11:04:32 | 5 | | | | | | | | | | |
| 11:08:35 | 4 | | | | | | | | | | |
| 11:09:01 | 3 | | | | | | | | | | |
| 11:10:30 | 1 | | | | | | | | | | |
| 11:15:25 | 0 | | | | | | | | | | |
| 11:16:36 | 1 | | | | | | | | | | |
| 11:20:36 | 2 | | | | | | | | | | |
| 11:21:06 | 3 | | | | | | | | | | |
| 11:21:13 | 1 | | | | | | | | | | |
| 11:22:13 | 2 | | | | | | | | | | |
| 11:24:23 | 1 | | | | | | | | | | |

Fig. 2B Transportation of the sand muck

| Time | Number of workers | Drill | Tank truck 1 | Tank truck 2 | Backhoe 1 | Dump truck 1 | Dump truck 2 | Oli feed vehicle | Dump truck 3 | Tanker | Backhoe 2 |
|-------------------|-------------------|-------|--------------|--------------|-----------|--------------|--------------|------------------|--------------|--------|-----------|
| 11:24:33 | 0 | | | | | | | | | | |
| 11:25:36 | 0 | | | | 1 | | | | | | |
| 11:27:06 | 0 | | | | 1 | 1 | | | | | |
| 11:30:06 | 0 | | | | 1 | | | | | | |
| 11:30:36 | 1 | | | | 1 | | 1 | | | | |
| 11:32:58 | 1 | | | | 1 | | | | | | |
| 11:34:14 | 1 | | | | 1 | 1 | | | | | |
| 11:37:38 | 1 | | | | 1 | | | | | | |
| 11:38:14 | 1 | | | | 1 | | 1 | | | | |
| 11:40:48 | 1 | | | | 1 | | | | | | |
| 11:42:37 | 1 | | | | 1 | 1 | | | | | |
| 11:46:20 | 2 | | | | 1 | 1 | | | | | |
| 11:53:30 | 1 | | | | 1 | 1 | | | | | |
| 11:57:42 | 1 | | | | 1 | | | | | | |
| 11:58:42 | 2 | | | | 1 | | | | | | |
| 11:59:02 | | | | | 1 | | | | | | |
| 12 : 01 ~ 13 : 04 | Lunch | | | | | | | | | | |
| 13:04:15 | | | | | 1 | | | | | | |
| 13:05:10 | 1 | | | | 1 | | | | | | |
| 13:05:52 | 1 | | | | 1 | | 1 | | | | |
| 13:07:56 | 1 | | | | 1 | | 1 | | | | |
| 13:11:31 | 1 | | | | 1 | | | | | | |
| 13:13:25 | 1 | | | | 1 | 1 | | | | | |
| 13:17:45 | 1 | | | | 1 | | | | | | |
| 13:18:30 | 1 | | | | 1 | | 1 | | | | |
| 13:24:00 | 1 | | | | 1 | | | | | | |
| 13:25:15 | 1 | | | | 1 | 1 | | | | | |
| 13:33:23 | 2 | | | | 1 | | | | | | |

Fig.2C Face excavation of the tunnel

| Time | Number of workers | Drill | Tank truck 1 | Tank truck2 | Backhoe 1 | Dump truck1 | Dump truck2 | Oli feed vehicle | Dump truck3 | Tanker | Backhoe2 |
|----------|-------------------|-------|--------------|-------------|-----------|-------------|-------------|------------------|-------------|--------|----------|
| 15:00:35 | 0 | | | | | | | | | | |
| 15:03:10 | | | | | 1 | | | | | | |
| 15:09:50 | 1 | | | | 1 | | | | | | |
| 15:11:27 | 1 | | | | 1 | 1 | | | | | |
| 15:12:00 | 1 | | | | 1 | | | | | | |
| 15:13:40 | 1 | | | | 1 | | | 1 | | | |
| 15:17:27 | 1 | | | | 1 | | | | | | |
| 15:19:27 | 1 | | | | 1 | 1 | | | | | |
| 15:22:20 | 1 | | | | 1 | | 1 | | | | |
| 15:22:56 | 1 | | | | 1 | | | | | | |
| 15:26:12 | 1 | | | | 1 | 1 | | | | | |
| 15:26:45 | 1 | | | | 1 | | | | | | |
| 15:29:03 | 1 | | | | 1 | | 1 | | | | |
| 15:30:03 | 1 | | | | 1 | | | | | | |
| 15:32:53 | 1 | | | | 1 | 1 | | | | | |
| 15:33:30 | 1 | | | | 1 | | | | | | |
| 15:36:25 | 1 | | | | 1 | | 1 | | | | |
| 15:36:35 | 1 | | | | 1 | | 1 | | | | |

Fig. 2D Transportation of the sand muck

| Time | Number of workers | Drill | Tank truck 1 | Tank truck 2 | Backhoe 1 | Dump truck 1 | Dump truck 2 | Oli feed vehcle | Dump truck 3 | Tanker | Backhoe 2 |
|----------|-------------------|-------|--------------|--------------|-----------|--------------|--------------|-----------------|--------------|--------|-----------|
| 14:34:55 | 2 | | | | | | | | | | |
| 14:35:20 | | | | | | | | | | | |
| 14:36:10 | 3 | | | | | | | | | | |
| 13:37:50 | 2 | | | | | | | | | | |
| 13:37:55 | 1 | | | | | | | | | | |
| 13:41:26 | | 1 | | | | | | | | | |
| 13:42:10 | 2 | 1 | | | | | | | | | |
| 13:44:35 | | 1 | | | | | | | | | |
| 13:45:50 | 1 | 1 | | | | | | | | | |
| 13:55:26 | 1 | 1 | | | | | | | | | |
| 13:56:36 | 3 | 1 | | | | | | | | | |
| 14:00:10 | | 1 | | | | | | | | | |
| 14:01:54 | 3 | 1 | | | | | | | | | |
| 14:27:59 | 3 | 1 | | | | | | | | | |
| 14:31:55 | 2 | 1 | | | | | | | | | |
| 14:34:15 | 3 | 1 | | | | | | | | | |
| 14:37:05 | 3 | 1 | | | | | | | | | |
| 14:41:21 | 3 | 1 | | | | | | | | | |
| 14:44:35 | 2 | 1 | | | | | | | | | |
| 14:45:25 | 1 | 1 | | | | | | | | | |
| 14:46:30 | 1 | | | | | | | | | | |
| 14:47:40 | 0 | | | | | | | | | | |
| 14:53:47 | 2 | | | | | | | | | | |
| 14:57:10 | 3 | | | | | | | | | | |
| 14:57:35 | 4 | | | | | | | | | | |

Fig. 2E Clearance of the day

| Time | Number of workers | Drill | Tank truck 1 | Tank truck2 | Backhoe 1 | Dump truck1 | Dump truck2 | Oli feed vehole | Dump truck3 | Tanker | Backhoe2 |
|----------|-------------------|-------|--------------|-------------|-----------|-------------|-------------|-----------------|-------------|--------|----------|
| 15:37:00 | | | | | 1 | | | | | | |
| 15:40:10 | | | | | 1 | 1 | | | | | |
| 15:40:50 | | | | | 1 | | | | | | |
| 15:43:10 | | | | | 1 | | 1 | | | | |
| 15:43:55 | | | | | 1 | | | | | | |
| 15:53:22 | | | | | 1 | | | | | | |
| 16:01:12 | | | | | 1 | | | | | | |
| 16:02:47 | | | | | 1 | 1 | | | | | |
| 16:03:25 | | | | | 1 | | | | | | |
| 16:05:58 | | | | | 1 | | 1 | | | | |
| 16:06:35 | | | | | 1 | | | | | | |
| 16:09:58 | | | | | 1 | | | | | | |
| 16:12:00 | | | | | 1 | 1 | | | | | |
| 16:12:40 | | | | | 1 | | | | | | |
| 16:13:15 | | | | | 1 | | 1 | | | | |
| 16:15:20 | | | | | 1 | | | | | | |
| 16:16:05 | | | | | 1 | 1 | | | | | |
| 16:18:27 | | | | | 1 | | | | | | |
| 16:18:27 | | | | | 1 | | 1 | | | | |
| 16:21:55 | | | | | 1 | | 1 | | | | |
| 16:22:30 | | | | | 1 | | | | | | |
| 16:25:25 | | | | | 1 | 1 | | | | | |
| 16:25:55 | | | | | 1 | | | | | | |
| 16:28:12 | | | | | 1 | | 1 | | | | |
| 16:28:52 | | | | | 1 | | | | | | |
| 16:31:42 | | | | | 1 | 1 | | | | | |
| 16:32:16 | | | | | 1 | | | | | | |
| 16:33:53 | | | | | 1 | | | | 1 | | |
| 16:34:43 | | | | | 1 | | | | | | |
| 16:35:43 | | | | | 1 | | 1 | | | | |
| 16:36:24 | | | | | 1 | | | | | | |
| 16:37:34 | | | | | 1 | 1 | | | | | |
| 16:38:08 | | | | | 1 | | | | | | |
| 16:40:25 | | | | | 1 | | | | 1 | | |
| 16:41:14 | | | | | 1 | | | | | | |
| 16:41:14 | | | | | 1 | | | | | | |
| 16:41:14 | | | | | 1 | | | | | | |
| 16:42:20 | | | | | 1 | | 1 | | | | |
| 16:42:55 | | | | | 1 | | | | | | |
| 16:46:35 | | | | | 1 | | | | | | |
| 16:49:40 | | | | | 1 | | | | | | |
| 16:59:25 | | | | | 1 | | | | | | |
| 17:06:55 | | | | | | | | | | | |
| 17:08:55 | | | | | | | | | | | |
| 17:14:00 | | | | | | | | | | | |

Fig.2F Face excavation of the tunnel

The most dangerous because workers often stood very close to heavy machines.

| Time | Number of workers | Drill | Tank truck 1 | Tank truck 2 | Backhoe 1 | Dump truck 1 | Dump truck 2 | Oli feed vehicle | Dump truck 3 | Tanker | Backhoe 2 |
|----------|-------------------|-------|--------------|--------------|-----------|--------------|--------------|------------------|--------------|--------|-----------|
| 15:00:35 | 0 | | | | | | | | | | |
| 15:03:10 | | | | | 1 | | | | | | |
| 15:09:50 | 1 | | | | 1 | | | | | | |
| 15:11:27 | 1 | | | | 1 | 1 | | | | | |
| 15:12:00 | 1 | | | | 1 | | | | | | |
| 15:13:40 | 1 | | | | 1 | | | 1 | | | |
| 15:17:27 | 1 | | | | 1 | | | | | | |
| 15:19:27 | 1 | | | | 1 | 1 | | | | | |
| 15:22:20 | 1 | | | | 1 | | 1 | | | | |
| 15:22:56 | 1 | | | | 1 | | | | | | |
| 15:26:12 | 1 | | | | 1 | 1 | | | | | |
| 15:26:45 | 1 | | | | 1 | | | | | | |
| 15:29:03 | 1 | | | | 1 | | 1 | | | | |
| 15:30:03 | 1 | | | | 1 | | | | | | |
| 15:32:53 | 1 | | | | 1 | 1 | | | | | |
| 15:33:30 | 1 | | | | 1 | | | | | | |
| 15:36:25 | 1 | | | | 1 | | 1 | | | | |
| 15:36:35 | 1 | | | | | | 1 | | | | |

Dangerous point; tunneling at face of tunnel

In the excavation of the face of the tunnel, the duration was 52 minutes, which was 13% in the whole work time of 6 hours and 33 minutes

| Place | Time | Number of worker | Drill car | Tank Truck |
|-----------------------|----------|------------------|-----------|------------|
| Around face of tunnel | 13:55:26 | 1 | 1 | |
| | 13:56:36 | 3 | 1 | |
| | 14:01:54 | 3 | 1 | |
| | 14:27:59 | 3 | 1 | Withdrawal |
| | 14:31:55 | 2 | 1 | |
| | 14:34:15 | 3 | 1 | |
| | 14:37:05 | 3 | 1 | |

DISCUSSIONS

- We concluded that the most dangerous work was 13% of the whole daily job of the tunneling work.
- The results suggested that risk reduction would be possible by making precise operational standard for each process.
- In further research, dangerous point detection would be made by ICT or IoT devices.